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TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 304

CORROSION EMBRITTLEMENT OF DURALUMIN

V. RESULTS OF WEATHER-EXPOSURE TESTS

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Bureau of Standards

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Light aluminum alloys of the duralumin type, that is, high-strength wrought alloys whose properties can be improved decidedly by heat treatment are of very great importance, especially in the form of sheet and tubes, for aircraft construction. The permanence of such materials when exposed to corrosive conditions such as may obtain in aircraft service should be known, however, with a high degree of certainty and precautionary measures taken to guard against any possible serious deterioration in service. To obtain reliable information along this line an investigation, the results of which form the basis of this series of reports (Reference 1), has been carried out at the Bureau of Standards in cooperation with the National Advisory Committee for Aeronautics, the Bureau of Aeronautics of the Navy Department, and the Army Air Corps. The leading manufacturers have also participated in the investigation by furnishing practically all of the materials needed. The investigation, which was started in the latter part of 1925, is still in progress and final and complete answers have not been reached on all points concerning the permanence of duralumin in service. The information which has been obtained, however, is of very considerable value to both manufacturers and users of aircraft and its publication at this time would seem to be warranted although possibly some of the statements made may be modified slightly in the light of future results.

Introduction

The conclusions expressed in the preceding reports of this series (Reference 1) concerning the deteriorating effect of intercrystalline corrosion on the tensile properties of sheet duralumin have been based upon the behavior of the material when subjected to conditions in the laboratory favorable to accelerated corrosion.

Any laboratory corrosion test, as judged from the practical point of view, is valuable only to the extent that it foretells what will, in all probability, occur in service. Such a test is most properly to be considered as a "pilot test," that is, a test which indicates the direction along which action may be expected to occur rather than as a truly quantitative test which would be expected to tell just how and to what extent the action would proceed. It is generally recognized that laboratory corrosion tests should be chosen with particular reference to the character of service expected for any particular type of metal, so far as it can be foreseen. Even when this requirement has been fulfilled, however, the question whether the actual service behavior of the material is in accordance and general agreement with predictions based upon such laboratory tests is always a pertinent one.

In this report are given the results which have been obtained, up-to-date, in the weather-exposure tests carried out on material of the same kind as was used in the laboratory corrosion tests. Although these exposure tests have not been completed, in the sense that all of the tests in the series initially laid down, have been accomplished, still the general trend shown by the results is so clear that a number of definite conclusions at this stage (subject, of course, to possible modification in the light of later results) are believed to be warranted.

II. Resume of the Results of Laboratory Tests

The fact is now well established that some sheet duralumin*, as well as some other high-strength aluminum alloys, under some conditions of use does not maintain its initial properties without impairment. The change may in some cases be very pronounced, indeed. This change as shown by the tensile properties, consists essentially in a marked lowering of the ductility of the material accompanied by a somewhat smaller proportional decrease in the tensile strength. Unlike the atmospheric corrosion of iron or steel, the change which may occur

*The name "duralumin" is used here as referring to the class of heat-treatable aluminum alloys in which the essential alloying elements are copper, magnesium, silicon and manganese, and not to the product of any particular manufacturer.

in sheet duralumin is not accompanied by any very marked surface indications.

A short resume of the important facts established by the laboratory study will suffice as a basis for the correlation of these results with those which have been obtained in the weather-exposure tests. The results of the laboratory corrosion tests of sheet duralumin have established, beyond all reasonable doubt, the following facts:

1. The change in sheet duralumin whereby the material is rendered relatively weak and brittle is a corrosion phenomenon localized along the grain boundaries and not a "spontaneous" internal change within the alloy such as, for example, a delayed phase change.

2. While this effect has been produced in the laboratory, to some extent at least, in all the compositions used, the presence of the constituent formed by the alloying of aluminum with copper appears to be most closely associated with this form of attack.

3. Chloride solutions are most potent in causing an intercrystalline attack. Solutions of the other halogens act similarly but are less active.

4. The rate of attack is accelerated by an increase of the temperature. At 70°C, the effect in dilute solutions was approximately four times that at room temperature in the same solutions.

5. The ordinary loss-of-weight method for determining the corrosion rate is not applicable in this problem. The testing of full-size tension bars after different degrees of attack is, by far, the best method to use. Certainly this method is practically the only one which will give reliable information as to the change in the mechanical properties of the metal, which is the information needed in this particular case.

6. In order to develop its highest tensile properties, duralumin must be heat treated. The method by which the heat treatment is carried out is very intimately related to the susceptibility of the heat treated duralumin sheet to embrittlement by intercrystalline attack. The heat treatment of duralumin consists essentially in two operations, quenching and aging. Heat treated sheet duralumin for which the quenching has been done in cold water is far more resistant to intercrystalline attack than the same which has been quenched in hot water before aging. Heat treated material for which the aging process has been accelerated by using an elevated temperature is much less resistant than if the aging is done at room temperature.

7. Cold-working of sheet duralumin by stretching, bending, and the like results in a condition which is somewhat favorable to intercrystalline corrosion, but this feature is a minor factor as compared with the differences in corrosion resistance which may result from improper heat treatment.

8. Properly heat treated sheet duralumin is not necessarily corrosion proof. Corrosion of the ordinary type may be expected to occur, hence, the need of protective coatings.

9. Oxide coatings formed by electrolytic treatment ("anodic process") as well as similar related coatings afford only very little protection in themselves. They must be kept well greased. The type of grease used is of secondary importance, the frequency of renewal is of prime importance.

10. Coatings of the spar varnish type are of only slight value. The addition of aluminum powder, however, reduces very greatly the permeability of such coatings to atmospheric moisture and also retards the deleterious effect of light on such coatings. Clear and pigmented varnish coatings as well as bitumastic enamel exposed in various solutions in laboratory corrosion tests failed by blistering. Aluminum pigmented rubber coatings have given excellent performance in laboratory corrosion tests.

11. Metallic aluminum coatings produced either by the metal spraying process or by rolling a duplex slab having a duralumin core and aluminum surfaces into sheet form, thereby producing a coating which forms an integral part of the finished sheet have given most excellent results. Protection of the "cut" edges of aluminum coated duralumin sheets appears not to be necessary if the sheet has been properly heat treated.

III. Methods of the Exposure Tests

The exposure tests, like those in the laboratory, were carried out upon full-size tension bars of sheet duralumin, 14-gauge material being used for nearly all of the tests. The chemical compositions of the different materials which include only commercial materials (in a few cases slightly modified) are summarized in Table I.

The specimens to which coatings were applied before exposure were heat treated by hot water quenching. According to the previous laboratory tests, such material would be expected to show a relatively low resistance to corrosion, hence, a breakdown of the "protective" coating under atmospheric influences would be expected to be shown by the change in the properties of the basic metal at a relatively early stage.

A preliminary set of exposure tests, started before the laboratory tests had progressed sufficiently far to show the pronounced influence of heat treatment upon the corrosion-resistance of sheet duralumin, was carried out with cold-water-quenched duralumin. The results of this series of tests are of value principally for their confirmation of the conclusions concerning the inter-relation of corrosion-resistance and mode of heat treatment used for duralumin. The results obtained, however, do not warrant the drawing of any very definite conclusions concerning the protective value of different coatings applied to cold-water-quenched duralumin sheet.

The exposure test racks were installed at three different locations representative of quite widely varying weather conditions. The locations are as follows: Naval Air Station, Coco Solo, Canal Zone; Naval Air Station, Hampton Roads, Virginia; and Bureau of Standards. The Coco Solo rack is illustrated in Figure 1. This rack, inclined as shown, faced the south and was situated on the breakwater. The Hampton Roads rack was situated in a very similar manner on a platform attached to the side of the pier, well above the high water line. The Bureau of Standards rack was located on the roof of one of the buildings and faced the south but, as shown in Figure 2, was raised only slightly above the horizontal position. The test bars were held in place in the cypress exposure rack at each end of the bars by a narrow strip of wood together with an outer reinforcing strip of sheet aluminum, both of which were fastened to the rack by screws at intervals of a foot or so. In addition to these three sets of specimens, a fourth set was kept in the laboratory in sealed glass containers. Soda lime was used to maintain a dry atmosphere within the containers, the specimens being supported on end on a grid of galvanized wire mesh placed well above the soda lime.

No change was made in the position of the specimens in any way during the exposure period. Necessarily, the exposure of the two surfaces of the specimens was therefore, not the same.

In this respect, however, the exposure tests paralleled service conditions more closely than did the laboratory corrosion tests.

In Table II are listed the different sets of specimens used in the exposure tests together with their initial tensile properties, and the treatment given to each, such as modifications in heat treatment, cold working, coating process and the like. Each set of specimens representative of each of the different variables consisted, in most cases, of ten specimens. In a few cases, a smaller number was used.

IV. Results

In Table III are given the results obtained in the preliminary set of weather-exposure tests (Hampton Roads Naval Air Station) with cold-water-quenched duralumin sheet. These results are included for comparison with those of the more extensive series of tests carried out at several different locations.

At successive intervals of several months, as shown in Figure 4, one specimen from each set of specimens from each of the racks was removed for testing. The tensile properties of the exposed specimens were determined and an examination of the microstructure made to determine whether or not intercrystalline corrosion had occurred. The appearance of the specimens shown in Figure 3 is typical of the results produced by exposure to the weather. In the Hampton Roads tests the surface change was somewhat less marked than was the case in the Coco Solo tests and in the Bureau of Standards exposure specimens the change was very much less marked. It is quite evident from Figure 3, without further discussion, that only in a qualitative sense can the surface appearance of the exposed bars be used as a measure of the effect of corrosion on the underlying metal.

The results of the tension tests of the exposed specimens, up-to-date, are summarized graphically in Figure 4. The initial properties, that is, those of the uncorroded materials have been included throughout for all of the sets of specimens as a "base line" for comparison. In those cases in which the evidence of the occurrence of intercrystalline attack was indisputable, this feature has also been indicated.

V. Discussion

The results of the exposure tests have definitely shown that sheet duralumin is not permanent under atmospheric exposure under all conditions. As a general rule, no noticeable or significant changes have been noted in the properties of duralumin when maintained under conditions such as render the chance of the occurrence of corrosion very remote. The conclusion that the impairment of the material which occurs is the result of corrosion, is believed to be fully warranted. Those cases in which deterioration of the material under atmospheric exposure occurs, very closely parallel the corresponding cases in the laboratory corrosion tests. The variations noted in the intensity of the attack under atmospheric exposure according to climatic conditions are in good accord with predictions based upon the laboratory tests. Exposure to marine atmospheric conditions is decidedly more effective in producing intercrystalline corrosion than exposure to inland atmospheres. Likewise, other conditions being the same, a warm climate is more severe than a colder one.

The susceptibility of sheet duralumin to corrosive attack by the intercrystalline method was found to be intimately related to the method employed in the heat treatment of the material, in both the exposure and accelerated corrosion tests. The agreement as to the character of the results in the two cases is exceptionally good (Figure 4, Sets 1-4 and 7-8). Without question, the use of hot water or oil as a quenching medium for the heat treatment of sheet duralumin is not to be recommended for material which must withstand severe weather conditions, despite the fact that the tensile properties of duralumin do not differ noticeably according to the different quenching media used. It will also be noted from Figure 4, that those materials which, after quenching, were aged at an elevated temperature (for example, Set 6 and 36) or which were heated somewhat after being allowed to age fully at room temperature (Set 17) are decidedly susceptible to intercrystalline corrosion. On the other hand, it should be noted that corrosion of the more familiar pitting type frequently occurred on materials which had been heat treated by approved methods, the drop in the tensile properties, especially elongation, accompanying this type of corrosion being quite marked in some cases (for example, Set 2).

Of the different variables in heat treatment, the subsequent behavior of sheet duralumin is affected most by the quenching rate and the aging treatment. The exposure test results have shown no difference in corrosion resistance resulting from varying the heating period prior to quenching. The results for Sets 4 and 5 (Figure 4) show no difference in the corrosion behavior of duralumin sheet heated for 15 or for 60 minutes at 500°C (920°F) prior to quenching.

If duralumin is quenched from a temperature somewhat below that at which the alloy constituents pass completely into the solid solution condition, the tensile properties are not so high as may be developed by using a higher quenching temperature. The corrosion resistance may also be less as shown by Set 10 (Figure 4).

Cold working of fully heat treated sheet duralumin did not render the material noticeably prone to intercrystalline attack in the atmosphere (Sets 12, 13, and 14). This was true regardless of whether the cold-worked conditions was a local one, such as produced by stretching the central portion or reduced section 10 per cent, or a more uniform cold-worked condition produced by cold rolling the entire bar sufficiently to increase its length 10 per cent. However, in the case when the material was not properly heat treated, cold working by stretching accentuated the embrittling intercrystalline attack (Set 16).

Variations in the composition of duralumin of the magnitude indicated in Table II are of minor importance so far as the resistance of the material to intercrystalline attack is concerned (Sets 20-25). The "initial" tensile properties of most of these alloys are considerably lower than those of the ordinary duralumin after heat treatment and are less suitable for this reason. Corrosion by pitting, however, in some seemed to be accentuated; for example, Set 24, of relatively high iron content, seems to be prone to this form of attack. No essential difference has been found to exist in the sheet duralumin made by different manufacturers if heat treated in the same manner (Compare BT materials with the others in Figure 4), although the composition often differs somewhat. Of the two alloys which differ markedly from the "duralumin composition," the one containing copper, alloy 25ST (Set 26) has shown marked intercrystalline attack, whereas in alloy 51S (Set 27) which contains no copper, only traces of intercrystalline attack were found after prolonged exposure to severe weather conditions.

The lack of permanence under exposure to the weather of most of the coatings used (Sets 28-39, Figure 4) is in good agreement with the indications of the laboratory tests. The use of duralumin which had been heat treated by quenching in hot water and, hence, quite susceptible to intercrystalline attack as a basis material for the application of the coatings has proved very satisfactory. An earlier series of exposure tests of a somewhat preliminary nature had shown the desirability of this, since if the duralumin sheet in its uncoated state has a high degree of resistance to corrosion, no conclusions concerning the real protective value of the coatings other than qualitative ones based upon visual inspection can be drawn.

The conclusion based on the laboratory results that of the various coatings, a surface layer of aluminum is by far the most dependable, has been borne out by the exposure tests on the aluminum-clad sheet. As is shown by Set 37 (Figure 4), however, an aluminum pigmented varnish may give excellent results under some conditions. That this is not always so, however, is shown by Set 28 (Figure 4).

Coatings consisting of a surface oxide film produced by the "anodic process" (Set 32) or closely related coatings formed by chemical means (Set 30) are undependable. The application of grease to such coatings at the outset, without subsequent renewal of the grease, has not materially increased the protection afforded by such coatings over the period covered by the tests 12 months). Likewise the use of a grease coating applied by rubbing which is then "bended" by the application of aluminum powder has not proved entirely dependable for the entire period during which the tests have been in progress. It is of interest to note, however, that for the relatively mild weather conditions obtaining in Washington and on the basis of which one might expect to draw nicer distinctions as to the merits of the coatings, the clear varnish and the "oxide" types of coatings have proved noticeably inferior to all of the others used.

In one important instance the weather exposure tests have not corroborated the laboratory tests. A rubber-like coating (thermoprene) pigmented with aluminum powder gave excellent protection against corrosion to duralumin in rather severe conditions in the laboratory. The difference observed when exposed to the weather is most probably to be attributed to a deterioration of the matrix of the coating which occurs despite the aluminum pigment added to prevent this. (The results for this type of coating are not given in Figure 4.)

In one rather important respect, weather-exposure tests of the kind described in this report may not duplicate service conditions in all respects. Most aircraft parts, in service, are always in a more or less stressed condition. Service tests to show the effect of stress on the corrosion behavior of duralumin parts are practically impossible. Laboratory tests on this point, however, are in progress. In brief, the tests consist in showing to what extent the tensile properties of sheet duralumin are affected by corrosion when the metal is under stress. Two general cases are being considered (a) simple or "static" tension, and (b) repeated flexural stress, the corrosive attack being carried out in the same kind of solution and by the same wet-and-dry corrosion method (repeated immersions at 15-minute intervals) as in the laboratory tests already carried out. The results of these "stress-corrosion" tests will form the basis of a later report. On the basis of the close parallelism which has already been found to exist between the results of the exposure tests and the laboratory corrosion tests of sheet duralumin, it is confidently expected that any pronounced change in the results of the laboratory tests resulting from the introduction of the variable of stress will be indicative of a corresponding behavior of the material under service conditions.

VI. Summary

1. In a series of weather-exposure tests of sheet duralumin upon which accelerated corrosion tests in the laboratory by the wet-and-dry corrosion method in a sodium chloride solution had already been carried out, a close parallelism between the results of the two kinds of tests was found to exist. Predictions based upon the results of the laboratory tests were, with but few exceptions, fulfilled in the exposure tests. In cases of disagreement in such tests, the results of the exposure tests are always accepted.

2. It has been shown by these tests that the lack of permanence or embrittlement of sheet duralumin which has been observed in some of this material in service under some conditions is

largely, if not entirely, to be ascribed to corrosion. A corrosive attack of an intercrystalline nature is very largely responsible for the degree of embrittlement produced. In the exposure tests, as indicated by the laboratory tests, the rate of embrittlement was greatly accelerated by a marine atmosphere and by a tropical climate.

3. The tests, both in the laboratory and in the field, were carried out upon full-size tension bars, the change in the tensile properties being used as a measure of the effect of corrosion. This method is, by far, the best in cases like the present, in which the tensile properties of the material undergo material change without a corresponding change in surface appearance.

4. The exposure tests confirmed the laboratory tests in showing that variations in composition of duralumin which do not result in wide departure from the ordinary "duralumin composition" are of almost negligible importance so far as corrosion behavior is concerned. Of the high strength aluminum alloys which differ materially in composition from duralumin, the alloy containing copper as the principal alloying element was most susceptible to intercrystalline attack.

5. Variations in the heat treatment procedure used for duralumin appear to be major factors in determining the susceptibility of the heat treated sheet to intercrystalline corro-

sive attack during exposure to the weather and likewise in accelerated corrosion tests. The quenching rate, as determined by the use of cold or hot water or oil as quenching media, and the aging treatment (room-temperature aging vs. accelerated aging) are the most important factors in this respect. The use of hot water or oil as a quenching medium for sheet duralumin or an accelerated aging treatment is not to be recommended for duralumin which must withstand severe climatic conditions, such as marine and tropical service.

6. Cold working of properly heat treated sheet duralumin by stretching or cold rolling does not affect very greatly the susceptibility of the material to embrittlement by intercrystalline attack when exposed to the weather. With improperly heat treated duralumin this factor is of much more importance.

7. The exposure tests have clearly shown that corrosion of the more familiar or pitting type may occur with duralumin. The effect upon the tensile properties although similar in character is, in most cases, decidedly less than that of the intercrystalline type. So far, it has not been possible to correlate definitely the tendency of the alloy toward this form of corrosive attack with any condition of the material resulting from any particular heat treatment or other condition.

8. The determination of the permanence of coatings on dura-

lumin under corrosive conditions, both in the laboratory or when exposed to the weather, has been most successfully done by applying the coating to tension bars of duralumin which had been improperly heat treated and, hence, quite susceptible to attack. The relatively rapid attack of the underlying or basis metal following the "breakdown" of the coating was shown in the tension tests of such specimens after exposure.

9. In this way, it has been shown that aluminum coatings are, by far, the most dependable. The useful life of clear varnishes is very short, the addition of aluminum "pigment" increases the permanence of the varnish very greatly. On the other hand, the addition of aluminum pigment to rubber-like coatings while decidedly successful in the laboratory, under exposure conditions has not given satisfactory results. Surface oxidation by "anodic" process and similar coatings have no lasting protective value unless well greased, and even when greased they have not proved to be resistant against severe exposure conditions, although with milder exposure conditions fairly satisfactory results have been obtained. Simple grease coatings "reinforced" with aluminum powder have given satisfactory service under mild exposure conditions but not entirely so for severe (marine) conditions.

10. Weather-exposure tests of the kind described here, while closely approximating service conditions, undoubtedly do

not duplicate them. Tests are now in progress for the purpose of showing how the corrosion behavior of sheet duralumin may be affected by a stressed condition coincident with the corrosive attack. However, the difference in the rate of attack of the material exposed to the weather in Washington and of similar material exposed to marine atmospheric conditions is so clear and the lack of permanence of most of the coatings used so unmistakable, that definite conclusions concerning the conditions which underlie the lack of permanence of duralumin and the protective measures which must be employed are believed to be fully warranted on the basis of the results of these exposure tests.

Bureau of Standards,
Washington, D. C.,
December, 1928.

R e f e r e n c e s

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Part I: Practical Aspects of the Problem. N.A.C.A. Technical Note No. 282. (1928)

Part II: Accelerated Corrosion Tests and the Behavior of High-Strength Aluminum Alloys of Different Compositions. N.A.C.A. Technical Note No. 283. (1928)

Part III: Effect of the Previous Treatment of Sheet Material on the Susceptibility to This Type of Corrosion. N.A.C.A. Technical Note No. 284. (1928)

Part IV: The Use of Protective Coatings. N.A.C.A. Technical Note No. 285. (1928)

TABLE I. Sheet Alloys Used in Corrosion and Exposure Tests

Designation of material	General Nature of Material	Composition (per cent)*										
		Cu	Fe	Si	Mn	Mg	Cr	Ni	Pb	Ca	Sn	Zn
17ST	Commercial alloy of the duralumin type (A.S.S.T. Handbook)	4.1	.34	.32	.51	.61	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
BT	Commercial duralumin (A.S.S.T. Handbook)	3.9	.51	.31	.58	.60	<.02	"	"	"	"	"
25S	Commercial alloy sheet (described in A.S.S.T. Handbook; 1929 ed., p.500)	4.2	.45	0.9	.68	.10		"		"	"	"
51S	Commercial alloy sheet (described in A.S.S.T. Handbook; 1929 ed., p.500)	.05	.38	1.0	.01	.61		"		"	"	"
A-17ST	Commercial alloy sheet (described in A.S.S.T. Handbook; 1929 ed., p.500)	2.5	.28	.24	.02	.40		"				
B-17ST	Commercial alloy sheet (described in A.S.S.T. Handbook; 1929 ed., p.500)	3.7	.36	.22	.02	.45		"				
63A	Prepared by manufacturer for this investigation, Fe content higher than in ordinary duralumin	3.8	1.15	.24	.50	.63		<.02				
58B	Prepared by manufacturer for this investigation, intended as a "low-copper" alloy	3.1	.55	.21	.50	.63		n.d.				
I-1	Prepared by manufacturer for this investigation, low Fe-Si ratio	4.2	.20	.20	.47	.47		"	n.d.	n.d.	n.d.	n.d.
I-2	Prepared by manufacturer for this investigation. Made from material of high purity, low Fe and Si contents	4.2	.08	.10	.47	.52		"	"	"	"	"
I-3	Duralumin type of alloy (17S)	4.2	.47	.34	.47	.50		"	"	"	"	"

*Chemical analyses by J. A. Scherrer, Chemist, Bureau of Standards.

n.d. = not detected.

TABLE II. Weather-Exposure Test Specimens.

Set No.	Material*	Treatment prior to exposure				Initial	
		Quenching temperature	Time in bath	Quenching media	Aging and coating	U. T. S. lb./sq.in.	Elongation (2") Per cent
1	17ST	500°C	15 min.	water 0°C	aged at room temperature	62,300	20.0
2	"	"	15 "	" 25°C	" " " "	63,600	22.0
3	"	"	15 "	" 100°C	" " " "	63,200	22.0
4	"	"	60 "	" 25°C	" " " "	63,100	20.0
5	"	"	15 "	" 0°C	aged 24 hours at 100°C	61,900	23.0
6	17ST	500°C	15 min.	water 0°C	aged 3 hours at 150°C	58,700	21.0
7	"	"	15 "	oil 0°C	aged at room temperature	60,800	20.0
8	"	"	15 "	" 25°C	" " " "	62,500	20.0
9	"	425°C	15 "	water 25°C	" " " "	43,500	20.0
10	"	"	60 "	" 25°C	" " " "	48,400	19.0
11	17ST	425°C	5 hr.	water 25°C	aged at room temperature	46,700	20.0
12	"	500°C	15 min.	" 0°C	aged 1 hr. at room temp. and stretched 10% in length	56,800	11.0
13	"	500°C	15 "	" 0°C	aged 96 hr. at room temp. and stretched 10% in length	65,800	12.0
14	"	500°C	15 "	" 0°C	aged 3 weeks at room temp. and cold rolled 10% in length	70,400	11.0
16	17ST	500°C	15 min.	water 100°C	aged 96 hr. at room temp. and stretched 10% in length	65,600	11.0
17	"	500°C	15 "	" 0°C	aged 96 hr. at room temp. and heated 5 hr. at 135°C	58,100	20.0
18	BT	500°C	15 "	" 25°C	aged at room temperature	63,700	20.0
19	BT	"	15 "	oil 25°C	" " " "	64,500	20.0
20	17ST-A	"	15 "	water 0°C	" " " "	37,100	24.0

*See note next page.

TABLE II. Weather-Exposure Test Specimens (Cont.)

Set No.	Material*	Treatment prior to exposure				Initial	
		Quenching temperature	Time in bath	Quenching media	Aging and coating	U. T. S. lb./sq.in.	Elongation (2") per cent
21	17ST-B	500°C	15 min.	water 0°C	aged at room temperature	51,500	22.5
22	I-1	"	15 "	" 0°C	" " " "	59,000	20.5
23	I-2	"	15 "	" 0°C	" " " "	52,400	20.0
24	63A	"	15 "	" 0°C	" " " "	51,800	19.5
25	58B	"	15 "	" 0°C	" " " "	51,700	20.0
26	25ST	520°C	15 min.	water 0°C	aged at room temperature	53,600	20.5
27	51ST	"	15 "	" 0°C	" " " "	53,700	27.5
28	17ST	500°C	15 "	" 100°C	coating, Cr varnish + Al paint	60,800	21.0
29	17ST	"	15 "	" 100°C	coating, pigmented oil	60,700	21.0
30	BT	"	15 "	" 100°C	coating, "Jirotka"	61,300	20.0
31	BT	500°C	15 min.	water 100°C	coating, "Jirotka" + lanoline	61,300	20.0
32	BT	"	15 "	" 100°C	coating, anodic	62,400	20.0
33	BT	"	15 "	" 100°C	coating, anodic + lanoline	62,600	20.0
34	I-1	"	16 "	" 100°C	coating, grease + Al powder	59,700	20.0
35	I-2	"	15 "	" 100°C	coating, Al pigmented varnish	60,000	21.5
36	25ST	520°C	15-30 min.	water	aged 8-15 hr. at 140°C - coating, Cr varnish	59,500	25.0
37	25ST	520°C	15-30 "	"	aged 8-15 hr. at 140°C - coating, anodic + Al varnish	59,400	21.0
38	I-3	500°C	15 "	" 100°C	aged at room temperature - coating, grease + Al powder	62,300	21.5
39	Alclad 17ST	None	As received			54,700	19.0

*The materials were made by the two American manufacturers of duralumin, that designated as BT by one manufacturer; all of the remainder by the other.

TABLE III. Exposure Tests of Sheet Duralumin.

This series of tests (Series 1) was started June 4, 1926. All specimens were heat-treated by quenching in cold water from 500-510°C from a fused nitrate bath

Set No.	Treatment prior to test	Material	Tensile Properties									
			Initial		5 months		11 months		17 months		23 months	
			U.T.S.	elong. (2")	U.T.S.	elong. (2")	U.T.S.	elong. (2")	U.T.S.	elong. (2")	U.T.S.	elong. (2")
1	Heat-treated, no coating	BD	61,500	19.5	57,200	16.0					58,100	13.0
		17SO	60,000	20.5			56,400	19.5	57,400	19.0		
2	Heat-treated, stretched 4%, no coating	BD	61,700	15.0	58,700	8.5	58,700	12.5	56,700	10.0		
		17SO	60,000	17.0							59,100	13.0
3	Black Valspar varnish	BD	61,500	19.5								
		17SO	60,000	20.5	57,100	19.0	57,300	19.0	55,800	17.0	57,300	15.5
4	Aluminum pigmented varnish	BD	61,500	19.5								
		17SO	60,000	20.5	58,500	19.0	57,900	19.5	58,000	17.0	55,200	18.0
5	Anodic oxidation treatment	BD	61,700	20.0								
		17SO	61,000	20.0	59,600	20.0	60,400	19.5	58,300	19.0	59,600	18.0
6	Same as (5) plus black Valspar	BD	61,700	20.0	58,600	17.5	57,800	14.5	57,600	16.5		
		17SO	61,000	20.0							55,200	11.5
7	Sand-blasted, metal sprayed with commercial Al, then heat-treated	BD	58,200	19.0					57,400	17.5		
		17SO	56,900	21.0	54,400	21.0	55,400	19.0			54,600	19.0
8	Same as (7) stretched 4% - no additional coating	BD	58,300	15.0	58,400	13.5	58,200	15.0				
		17SO	59,100	15.0					54,400	15.5	55,600	15.0

TABLE III. Exposure Tests of Sheet Duralumin (Cont.)

Set No.	Treatment prior to test	Material	Tensile Properties: Initial U.T.S.	Initial elong. (2")	5 months U.T.S.	5 months elong. (2")	11 months U.T.S.	11 months elong. (2")	17 months U.T.S.	17 months elong. (2")	23 months U.T.S.	23 months elong. (2")
9	Same as (8) plus black Valspar	BD	58,000	15.0	58,400	12.5	58,800	15.5	57,400	14.0	59,400	15.0
		17SO	58,500	15.0								
10B	As received, no further treatment	I-3	62,700	21.5	62,700	18.0	60,600	17.5	59,200	12.5	61,500	17.0
10A	Like 10B, coated with "bitumastic enamel," then metal sprayed with Zn and Al	I-3	62,500	21.0	62,200	21.0	60,800	21.5	61,400	17.5	62,500	22.0

Note: BD material furnished by Baush Machine Tool Company.
17SO " " " Aluminum Company of America.
I-3 " " " Aluminum Company of America, is representative of commercial heat-treated duralumin.

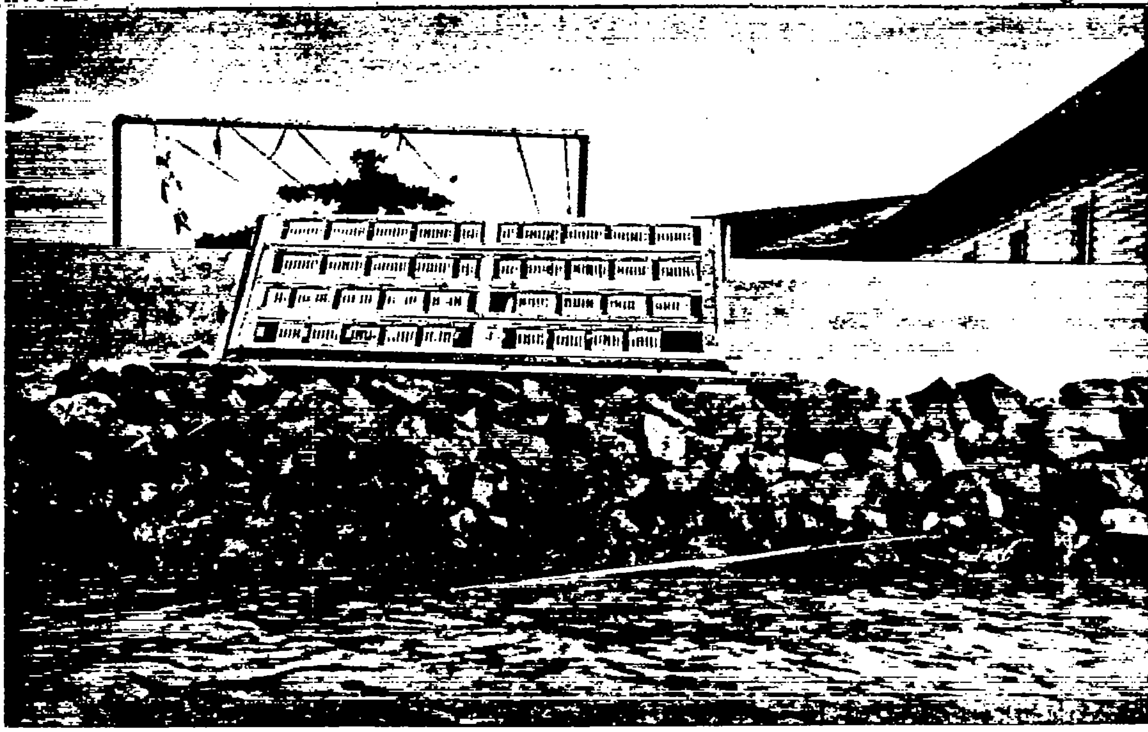

Fig.1 Exposure rack and specimens, Coco Solo Naval Air Station, Canal Zone

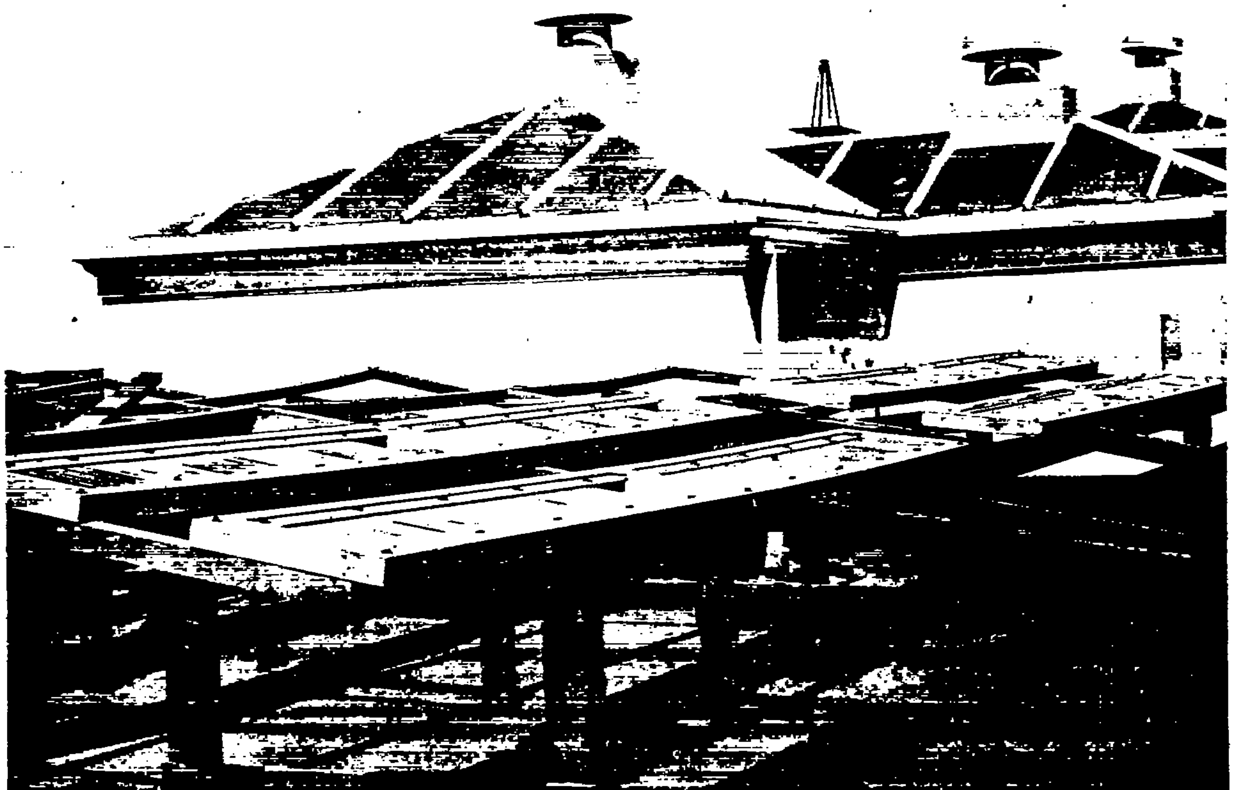

Fig.2 Exposure rack and specimens, Bureau of Standards roof

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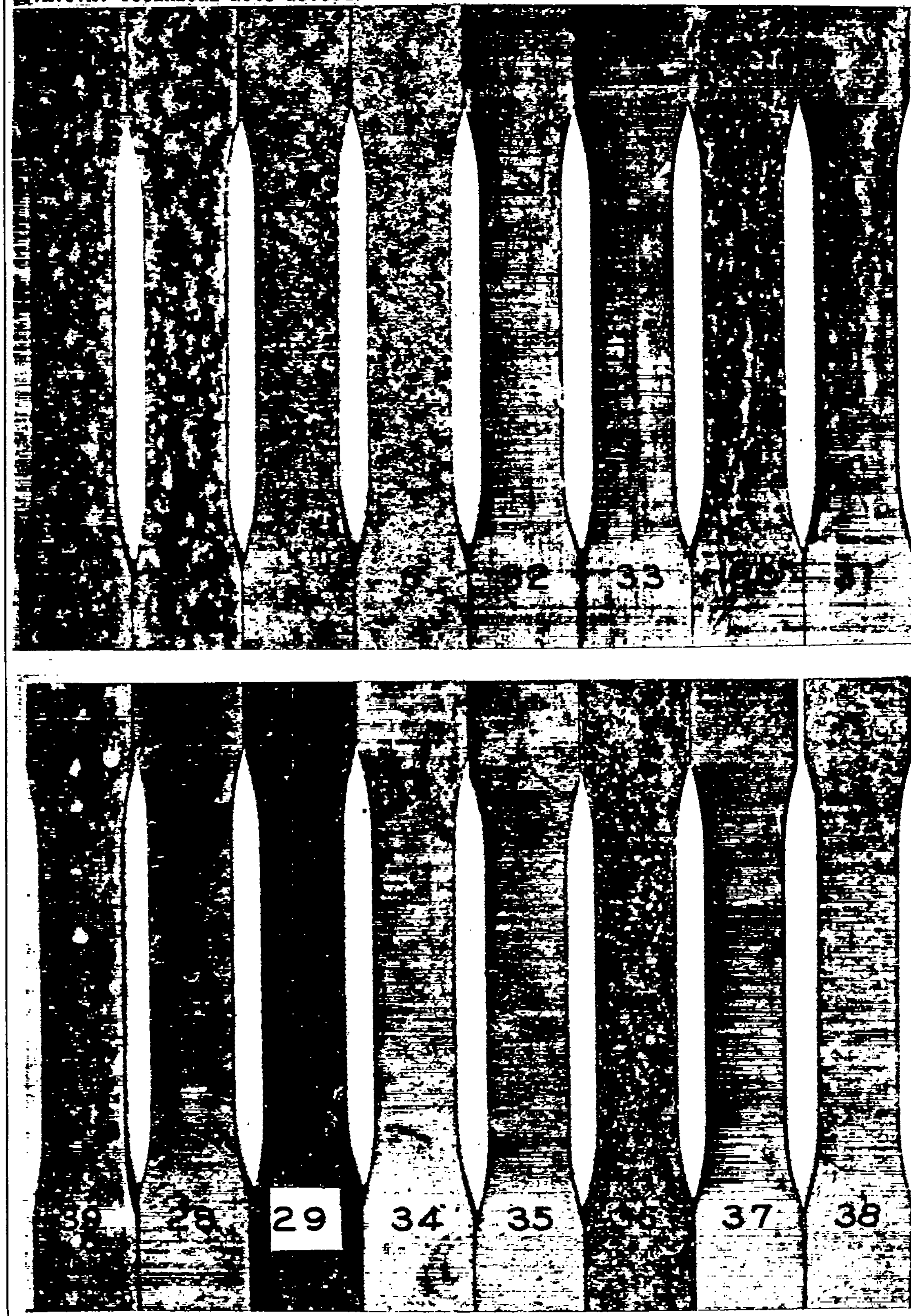

Fig.3 Surface appearance of representative specimens from the Coco Solo rack after 4 1/2 months exposure.

The photograph shows the under or partially protected surface of the specimens

For the significance of the numbers, refer to Table II.

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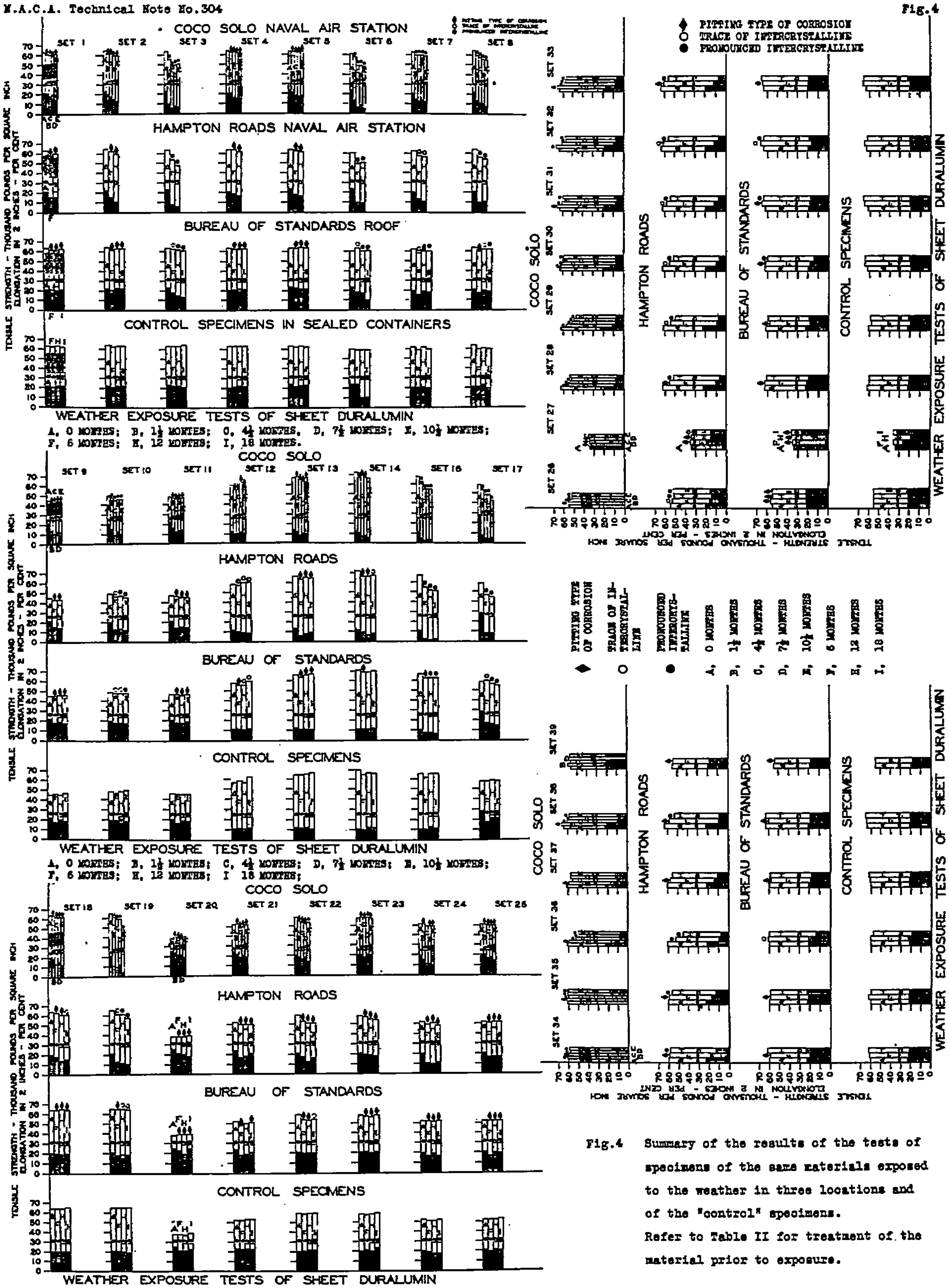

Fig.4 Summary of the results of the tests of specimens of the same materials exposed to the weather in three locations and of the "control" specimens.
Refer to Table II for treatment of the material prior to exposure.